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54 Method of forming a porous preform.

57 A porous glass optical waveguide preform (47) is formed by depositing a coating of glass particulate material on the lateral surface of a core (46) which may be a porous glass body continuously produced by the axial deposition of glass particles. The core (46) rotates and moves longitudinally in one direction with respect to two flame hydrolysis burners (40, 41) which emit streams of glass particles having different compositions. In addition, the two burners (40, 41) reciprocatingly move with respect to a portion of the length of the core (46). The speed of each burner (40, 41) varies as it traverses along its path of reciprocating motion. The thickness of the layer produced by a burner at a given point is inversely related to the speed of the burner as it passes that point. The layers formed by the completion of a single traverse by both burners combine to form a conically-shaped layer (51), the composition of which varies from the base toward the apex thereof. The conically-shaped layers (51), which are adjacently located longitudinally along the preform, combine to form a cylindrically-shaped portion of the preform.

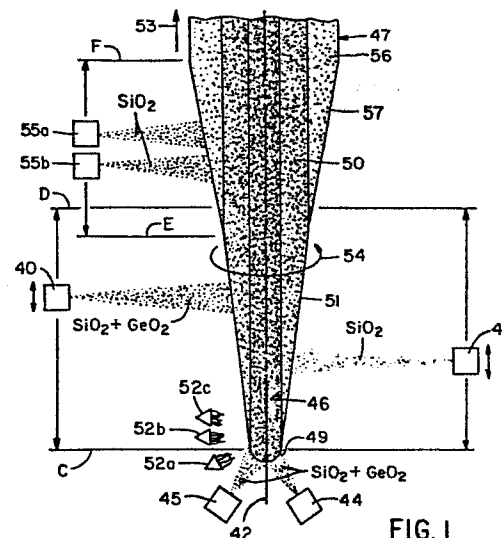


FIG. 1

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Method of forming a porous preform

Optical waveguide fibres have been greatly improved during the last decade. Fibres exhibiting very low losses are generally formed by chemical vapour deposition (CVD) techniques which result in the formation of extremely pure materials. In accordance with these techniques, optical waveguide preforms can be formed by depositing and thereafter consolidating glass particles called "soot" on the surface of a mandrel by outside vapour deposition (OVD), or on the inside surface of a tube which later forms at least a portion of the cladding material, or by some combination of these techniques.

Although CVD techniques of forming optical waveguide preforms result in the formation of optical waveguide fibres have extremely low attenuation, such techniques are relatively expensive. Fibre manufacturing cost can be lowered by increasing preform size or by continuously drawing fibre from a preform while the preform is being formed. Both of these cost reducing techniques decrease the number of preform handling and processing steps per unit of fibre length.

The OVD technique readily lends itself to cost reduction modifications. Initially, preforms were made larger by increasing the diameter. This was accomplished by traversing the burner longitudinally along the soot preform and adding thereto additional layers of increasing radius. Thereafter, axial techniques were developed whereby one or more burners or other soot depositing nozzles were directed axially toward a starting member. As the thickness of the deposited soot layer increases, the starting member moves away from the burners. Axial vapour phase oxidation techniques are described in U.S. Patents Nos. 3,966,446, 4,017,288, 4,135,901, 4,224,046 and 4,231,774.

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A hybrid technique whereby a core is formed by axial vapour phase oxidation, and a cladding layer is simultaneously deposited on the core by radially inwardly directed glass soot streams is described in U.S. Patent Nos.

5 3,957,474, 4,062,665 and 4,310,339. As the core is formed, it is withdrawn from the burners or nozzles which formed it. The cladding is deposited by stationary burners or nozzles.

Substantially continuous methods of forming optical waveguide fibres by vapour phase oxidation techniques are
10 described in U.S. Patent No. 4,230,472 and U.K. Patent Application GB 2,023,127A.

Deposition rate in the aforementioned CVD processes is determined by the temperature gradient within the gas stream in which the soot particles are entrained (see the
15 publication, P. G. Simkins et al., "Thermophoresis: The Mass Transfer Mechanism in Modified Chemical Vapour Deposition", Journal of Applied Physics, Vol.50, No. 9, September, 1979, pp. 5676-5681). Thermophoresis drives the soot particles from the hotter parts of the gas stream
20 toward the cooler parts. Because the substrate or preform surface is usually cooler than the surrounding gas stream, the action of thermophoresis tends to drive the soot particles toward the preform surface. When a surface is nearly as hot as the surrounding gas stream, the temperat-
25 ure gradient is low. Thus, the thermophoresis effect is minimal, and the deposition rate is low. However, when the surface temperature of the preform surface is low, the thermophoresis effect due to the large thermal gradient results in a relatively high deposition rate.

30 In the aforementioned hybrid technique, a burner is continuously directed at one position on the preform. Thus, the preform surface becomes hot, and the rate of deposition is limited by the small temperature gradient between the preform surface and the soot-containing gas stream.

35 U.S. Patent 4,378,985 achieves an enhancement in deposition rate and efficiency by advantageously using the

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thermophoresis effect. In accordance with that method a porous glass optical waveguide preform is formed by depositing a coating of glass particulate material on the lateral surface of a core which may be a porous glass body produced by the axial deposition of glass particulate material. The core rotates and moves longitudinally in one direction with respect to a flame hydrolysis burner. In addition, the burner reciprocatingly moves with respect to a portion of the length of the core. The reciprocating motion of the burner relative to the core material permits the soot preform to cool down between successive burner passes, thus increasing deposition rate due to enhanced thermophoresis. The continual longitudinal movement between the burner and the core material permits the formation of relatively long preforms or the continuous production of preforms from which fibres may be continuously drawn, if so desired. To form a radial gradient in the refractive index of the preform, the composition of the reactant vapour fed to the burner is varied in accordance with the position of the burner along its reciprocating path. During the reciprocating movement of the burner a conical section of preform is formed.

It is an object of the present invention to provide an efficient method and apparatus for forming graded index or other non-uniform refractive index optical fibre preforms.

Briefly, the method of the present invention is of the type wherein a cylindrical core member is rotated about its longitudinal axis, and a plurality of layers of glass particles are deposited thereon to build up a first coating of given thickness. In accordance with one aspect of the present invention, the layers are formed by directing toward a lateral surface of the core member first and second streams of glass particles, the composition of the first stream being different from that of the

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second stream. The first stream is reciprocatingly moved along a given length of the core member. The second stream is reciprocatingly moved along a length of the core member which includes the given length. The velocities of the first and second stream vary during the formation of the first coating, the function by which the first stream varies being different from the function by which the second stream varies. The velocity of each stream is a function of the radius of that part of the first coating that is being formed thereby.

In accordance with a first embodiment, the velocity of each stream is a function of the radius of the cylindrical layer being deposited. The first stream may deposit particles of glass having a refractive index lower than that of the particles of the second stream. The velocity of the first stream decreases, and the velocity of the second stream increases as the radius of the first coating increases. The instantaneous direction of movement of the first stream may be opposite that of the second stream.

In accordance with another embodiment the core member is longitudinally moved in one direction, and each of the first and second streams traverses the core member at a velocity that is a function of the position of the stream along its path of reciprocation, the velocity versus position function of the first stream being different from that of the second stream. The combined effects of the streams are such that continued performance of the method results in the deposition of a particulate material coating of given thickness on the core, the coating thickness tapering from the given thickness to zero thickness in the region of reciprocating movement of the streams. The refractive index of the particles of the second stream is greater than that of the particles of the first stream. The velocity of the first stream is less than that of the second stream when they are depositing on the relatively thick portion of the coating. The velocities of both streams change as they longitudinally traverse toward the

thinner region of the deposit. The combined action of both streams results in the formation of a porous preform having a tubular section having a gradient refractive index.

5 The core member may comprise a temporary madrel or an optical quality glass rod that will eventually form the central region of the resultant optical fibre. In one embodiment the core member is a continuously formed porous glass member. One or more streams of glass particles may
10 be directed toward the end portion of the core member to continuously build up the length thereof as the core member is longitudinally moved so that the end surface remains at a substantially fixed position. In order to lessen the severity of discontinuities which may exist at
15 the outer region of such a continuously formed core member, the streams of glass particles that are axially directed toward the core member end surface can be moved in an oscillatory fashion along an arcuate path while the streams are continuously directed toward the end surface.

20 The present invention also includes apparatus for performing the aforementioned functions.

 Practising the above-described methods results in the formation of a porous preform comprising a cylindrical-ly-shaped region formed by a plurality of adjacent layers.
25 Each layer is formed of two sublayers of glass particles, the first sublayer having a refractive index greater than that of the second sublayer. Each sublayer comprises two sections, a first section of the first sublayer being adjacent to one of the immediately adjacent layers and
30 the second section of the first sublayer being adjacent to the opposite immediately adjacent layer.

 In one embodiment wherein the layers are cylindric-ally shaped, the thickness of the first sublayer decreases with each successive layer of larger radius.

35 In an embodiment wherein the layers are conically-

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shaped, the thickness of the first sublayer decreases toward the base of each conically-shaped layer.

In the accompanying drawings:

Figure 1 is a schematic illustration of the apparatus of this invention,

Figure 2 illustrates the angular orientation of various components of Figure 1 with respect to the preform axis,

Figure 3 is a front elevational view of a variable speed burner traversing mechanism,

Figure 4 shows the face of a burner which may be employed with the apparatus of the invention,

Figure 5 schematically illustrates in block diagram form a system for controlling the speed of burners 40 and 41 of Figure 1,

Figure 6 is a graph of burner velocity v. burner position,

Figure 7 is a schematic illustration of a reactant delivery system which may be employed with the apparatus of Figure 1,

Figures 8 and 9 are graphs of weight percent GeO_2 v. core diameter for two optical waveguide preforms formed by employing two different embodiments of the present invention,

Figure 10 shows an apparatus for rocking axial burners about the tip of a preform,

Figure 11 is a cross-sectional view taken along line II-II of Figure 10,

Figures 12 and 13 are schematic representations of the burners at different times during their movement cycle,

Figure 14 is a plan view of an apparatus for changing the direction of a soot stream,

Figure 15 is a schematic representation illustrating burner movement when the apparatus of Figure 14 is employed; also illustrated is a burner traverse path having both linear and arcuate sections,

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Figure 16 illustrates a further embodiment of an apparatus in accordance with the present invention,

Figure 17 illustrates a continuous fibre drawing process,

5 Figure 18 is a partial cross-sectional view of a porous preform which may be produced by the method of the present invention,

Figure 19 illustrates a further embodiment of an apparatus in accordance with the present invention, and

10 Figure 20 is a partial cross-sectional view of a porous preform formed by the apparatus of Figure 19.

One embodiment of the present invention is illustrated in Figures 1 to 5. This apparatus comprises two laterally disposed burners 40 and 41 which are employed to deposit
15 the outer region of the graded index traverse.

Outer core region 50 can be formed with a radial refractive index gradient by appropriately controlling the ratio of the speeds of burners 40 and 41 as they traverse each point along axis 42 between extremes C and
20 D of their path. For example, if burner 40 deposits SiO_2 doped with 30 weight percent GeO_2 and the prescribed profile requires 25 weight percent GeO_2 at a particular point, then burner 41 would move about five times faster than burner 40 past that particular point. Likewise, if
25 the composition required at another radius within outer core region 50 is 5 weight percent GeO_2 then burner 41 would move about 1/5 as fast as burner 40 at that point. The mechanical implementation of the invention is simplified if the following conditions exist: (1) that burner 40
30 deposits a composition containing a somewhat higher dopant concentration than that required at any part of the profile and (2) that the outermost region of the core contains a small amount of the core dopant. One further condition which makes the mathematics simpler is that
35 equal times be set for burners 40 and 41 to make the round

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trip between points C and D. The graph of Figure 6 shows the calculated speeds of burners 40 and 41 at each burner position between points C and D in order to form a graded index profile having an alpha value of 2.

5 An apparatus suitable for traversing a burner at a variable speed between two points is shown in Figure 3. A vertical table 65 is situated on that side of preform axis 42 opposite exhaust hood 39 (see Figure 4). Only the apparatus employed in the vertical movement of burner
10 41 is shown in this Figure, similar apparatus being employed in the movement of burners 40 and 55. Vertical shaft 66 is supported in spaced relationship with respect to table 65 by supports 67 and 68. Two support ribs 69 are connected to plate 71. Burner 41 is mounted on an x-y positioner 70
15 which is affixed to plate 71. The ends of ribs 69 are provided with bushings 72 through which shaft 66 passes. Also mounted on plate 71 is a reversing mechanism 73. A variable speed drive motor 74 is coupled to shaft 75
20 which is vertically supported by bearings 76. Shaft 75, which rotates in only one direction, operatively engages reversing mechanism 73. To provide greater stability, plate 71 can be provided with one or more additional sets of ribs having bushings which are slidably mounted on additional vertical shafts.

25 Motor 74 is a stepping motor, the rotational speed of which depends upon the frequency of an input signal applied thereto. Shaft 75 has a smooth surface which contacts an angularly orientated member (not shown) which forms a part of reversing mechanism 73. The vertical
30 speed of plate 71 is determined by both the rotational speed of shaft 75 and the specific orientation or switched state of the angularly orientated member with respect to the shaft. When reversing mechanism 73 contacts one of the stops 77, which are affixed to table 65, the angularly
35 orientated member of mechanism 73 is mechanically switched to an opposite state whereby the direction of movement

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of plate 71 reverses. Obviously, other comparable reversible drive mechanisms could be employed. For example, a rack and pinion gear arrangement could be used in conjunction with a reversible motor.

5 Because of the number of components which had to be used within a confined space, a relatively small burner was employed. The front face 79 of the burner illustrated in Figure 4 is about 20 mm by 32 mm. Centrally disposed on face 79 is an orifice 80 for delivering a stream of
10 reactant vapours. Orifice 80 is surrounded by a circular array of orifices 81 located on a radius of 2.6 mm. Oxygen issues from orifices 81 to form a so-called "inner shield" of oxygen around the reactant vapour stream. Premixed oxygen and fuel gas issue from orifices 82 which are
15 disposed on face 79 in a square array which is about 9 mm between opposed linear arrays.

Figure 5 shows in block diagram form a circuit which may be employed to control the speed of the drive motor. The computer system 84 may consist of a PDP 11/34 mini
20 computer having a CAMAC interface. Computer 84 stores a series of digital numbers, each one corresponding to the velocity of the burner at each point along its traverse. The computer determines burner velocity and sends a digital number to digital-to-analog converter 85. The
25 output of converter 85 is coupled to voltage-to-frequency converter 86 which transmits a series of square wave pulses to both amplifier 87 and presettable up-down counter 88. Counter 88 keeps track of the position to which the burner has been driven by counting the pulses transmitted thereto from converter 86. In the specific
30 example described hereinbelow computer 84 provided converter 85 with a digital number one hundred and one times during the traverse of a burner between limit switches 89.

35 Counter 88 is preset by computer 84 to a number corresponding to the number of steps that the motor is to be driven before a speed change is to be made. As each

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step is made, the counter is decremented by one. When the counter underflows (counts down to -1) it generates an interrupt signal which is transmitted to computer 84. The computer acknowledges the interrupt signal by running the subroutine which changes the motor speed, when necessary, by transmitting a new digital signal to converter 85, and it also resets counter 88. When a limit switch 89 is contacted by plate 71, the closing of that switch causes interrupt module 90 to generate an interrupt signal which is transmitted to computer 84 to inform the computer that reversing mechanism 73 has been mechanically switched. The interrupt signals generated by module 90 are used by the computer to keep the burner in proper sequence, not only as regards the corrected velocity with respect to position along the preform, but also with respect to the other burners.

The apparatus of Figures 1 through 5 was employed in the following manner to form an optical waveguide fibre. In this specific example, the system of Figure 5 consisted of the following components. Reversing mechanism 73 was a Uhing Model 3 RG 30/35. Motor 74 was a Slo-Syn stepping motor, the shaft of which rotated 1/200 revolution for each input pulse. Amplifier 87 was a Model ST105 packaged translator. Both motor 74 and amplifier 87 were manufactured by the Superior Electric Co. The translator is a high speed motor control device which receives pulses from converter 86 and converts those pulses into the switching sequence needed to drive the motor in steps. Converter 85 was a Model 3112 8-Channel, 12-bit D/A converter. Converter 86 was a Model 3560 Quad V-F converter. Counter 88 was a Model 3640 4-Channel, Up-Down presettable counter. Converters 85 and 86, counter 88 and the CAMAC interface for computer 84 were manufactured by Kinetic Systems Corp.

Burner position and orientation will be defined by the distance between the burner face and preform axis 42

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and the angles between the burner axis and both preform axis 42 and plane 43. The burner axis is herein defined as that line perpendicular to the burner face about which the initially-formed portion of the soot stream is symmetrical. End surface 49 of preform 47 was continuously formed by axial burners 44 and 45 which were located about 10 cm from surface 49. The axes of burners 44 and 45 formed angles of 50° and 70° , respectively, with preform axis 42, and the angle α between the axis of each of these burners and plane 43 was 30° . Lateral burners 40 and 41 were located 14 cm from axis 42, and both traversed a distance of 18.4 cm along preform 47 between points C and D, thereby generating conically-shaped region 51. The angles β and ϕ between burners 40 and 41 and plane 43 were 37° and 45° , respectively. End point C of the traverse of burners 40 and 41 was such that the soot deposited by those burners at end point C slightly overlapped the deposit being formed by burners 44 and 45, point C being about 1.5 cm above the tip of end surface 49. The velocities of burners 40 and 41 varied with respect to burner position in accordance with the curves of Figure 8. The velocities of burners 40 and 41 at point C were 4 cm/sec and 8 cm/sec., respectively, and at point D were 16 cm/sec and 3.2 cm/sec., respectively. Burners 55a and 55b, which consisted of two burners mounted in tandem and located 15.2 cm from axis 42, traversed along axis 42 between points E and F at a constant velocity. In this embodiment, burner 55b deposited pure silica whereas burner 55a functioned as an auxiliary burner and merely supplied heat. Burner 55b traversed about 25 mm past the end point D of traverse of burners 40 and 41. Point F was located 17.8 cm above point E.

A drawing mechanism and chuck similar to those of U.S. Patent 4,378,985 were employed. Preform 47 was traversed upwardly as illustrated by arrow 53 and rotated as

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illustrated by arrow 54. To reduce mechanical vibration, three small shock absorbers were employed. Each of these shock absorbers comprised an air dashpot, one end of which was fixedly mounted, the other end having a wheel which rode on the rotating mandrel.

The flow rates in litres/min of gases and reactant vapours to the various burners were as tabulated in Table 1, and the fuel gas and oxygen flow rates for the auxiliary burners were as set forth in Table 2. Each of the soot-producing burners was provided with a 7 cm long cylindrical shield of the type to be described in conjunction with Figure 14.

TABLE 1

		<u>Burner No.</u>					
		<u>40</u>	<u>41</u>	<u>44</u>	<u>45</u>	<u>55a</u>	<u>55b</u>
15	Flame						
	Fuel Gas	2.20	2.77	0.97	0.85	2.42	4.26
	Oxygen	1.15	2.00	0.33	0.29	2.27	3.02
	Inner Shield						
20	Oxygen	4.73	4.73	0.73	0.89	4.73	4.73
	Reactants						
	SiCl_4	0.47	0.49	0.47	0.29	--	0.48
	Oxygen	0.62	0.64	0.62	0.38	--	0.63
	GeCl_4	0.073	--	0.032	0.42	--	--
25	Oxygen	0.29	--	0.129	0.169	--	--

TABLE 2

		<u>Auxiliary Burner No.</u>		
		<u>52a</u>	<u>52b</u>	<u>52c</u>
30	Fuel Gas	1.39	1.28	0.37
	Oxygen	1.15	1.06	0.49

The reactant delivery system employed in this example is schematically illustrated in Figure 7. The liquid reactants SiCl_4 and GeCl_4 were maintained at 40°C and 35°C in reservoirs 60 and 61, respectively. Oxygen was bubbled through the liquid SiCl_4 , and the resultant mixture of

oxygen and SiCl_4 vapours was fed to burners 40, 41, 44, 45 and 55b via a plurality of valves and flowmeters. Oxygen was also bubbled through the liquid GeCl_4 , and the resultant mixture of oxygen and GeCl_4 vapours was fed to
5 burners 40, 44 and 45 via a second plurality of valves and flowmeters. The temperature of the liquid reactant and the flowmeter reading for both oxygen and reactant being known, the flow rates of the oxygen and the reactant vapour were calculated. The calculated values are set
10 forth in Table 1. For this reason, the flow rate of oxygen is listed twice under "reactants", each listing being for oxygen flow rate from a respective bubbler. A preform was made and consolidated, no attempt being made to dry the preform. The consolidated preform was drawn into a fibre
15 having an attenuation of 2.9 dB/km at 850 nm and 1.54 dB/km at 1060 nm.

The maximum deposition rate for steady state deposition on the apparatus of Figures 1 to 5 was 4.7 g/min. Preforms fabricated under these conditions approached
20 13 cm. in diameter. A typical microprobe analysis of the GeO_2 concentration across the diameter of the core region of a preform is shown in Figure 8. The axial core region, which is located between about 8,000 and 18,000 microns, has a GeO_2 concentration gradient represented
25 by curve 90, and the lateral core regions have GeO_2 concentration gradients represented by curves 91 and 92. Large depressions 93 and 94 occur in the concentration gradient between the axial core region 90 and the lateral core regions 91 and 92, respectively. The loss of germania
30 evidenced by depressions 93 and 94 is probably caused by a low temperature zone in that region of preform 47 between the axially-produced core 46 and laterally-produced core 50.

Optical fibres of the type formed in accordance with the above example are useful for propagating optical
35 signals over relatively long distances because of the low loss thereof. However, because of the presence of

depressions 93 and 94 in the core dopant concentration, the refractive index gradient of such a fibre would have similar depressions. A multimode fibre having such index depressions would have a bandwidth not much higher than
5 that of a step index fibre. However, a single mode fibre having refractive index depressions within the core can provide high bandwidth. Such a single mode fibre is disclosed in Japanese Kokai 104040/83.

As mentioned above, it is desirable to minimize the
10 refractive index depressions 93 and 94 of Figure 8 in order to obtain high bandwidth multimode optical fibres. An optical waveguide preform having the improved germania concentration gradient illustrated in Figure 9 was obtained by modifying the procedure specified in the above-described
15 example. In this embodiment point C was located about 1 to 2 cm below end surface 49 of the preform (see Figure 3). Indeed, burners 40 and 41 were traversed beyond end surface 49 a distance sufficient that the soot streams therefrom no longer deposited on the preform. Also,
20 burners 44 and 45 were oscillated about end surface 49 in the manner described hereinbelow. Apart from the changes described immediately above, the method which resulted in a preform represented by the microprobe profile of Figure 9, including flow rates to the burners, is
25 similar to that described in the first example.

The apparatus for oscillating burners 44 and 45 about end surface 49 is illustrated in Figures 10 and 11. Burners 44 and 45 are mounted on platform 94 which is connected by arm 95 to sleeve 96 which is rotatably mounted
30 on shaft 97. Worm gear 98, which is rotated by motor 99, engages circular gear 100 which is affixed to sleeve 96. This mechanism can be employed to oscillate burners 44 and 45 along an arcuate path below preform end surface 49 as indicated by arrow 101 by continuously changing the direc-
35 tion of rotation of motor 99.

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The movement of burners 40, 41, 44, 45 and 55 may be synchronized in the manner illustrated in Figures 12 and 13. As shown in Figure 12, burners 44 and 45 have oscillated to one extreme position when burner 40 has reached its lowest position. Burner 41 is at the top of its path, and burner 55 in the centre of its path and is moving upwardly. The arrow connected to each burner indicates the direction in which it is moving or in which it is about to move.

As shown in Figure 13, burners 44 and 45 are in the middle of their oscillatory path when burners 40 and 41 are in the middle of their paths of movement. At this time burner 55 has just reached the top of its path.

When burners 44 and 45 reach the opposite position of their swing, burner 41 will have reached its lowest point. At this time burner 40 will be in its topmost position, and burner 55 will be moving downwardly through the middle of its path.

In the final phase of burner movement, burner 55 reaches the bottom of its path as burners 40 and 41 are in the middle of their paths, burner 40 moving downwardly and burner 41 moving upwardly. At this time, burners 44 and 45 are in the middle of their oscillatory path.

A further apparatus for smoothing the germania concentration profile is illustrated in Figure 14, wherein elements similar to those illustrated in previously discussed Figures are represented by primed reference numerals. An x-y positioner comprising separately movable sections 70a and 70b is mounted on plate 71'. Burner 40' is affixed to axle 102 which is rotatably mounted in bearings 103. A cylindrically-shaped shield 104 is affixed to burner 40' and spaced from the burner face by about 4 mm. A worm gear 105 affixed to axle 102 is operatively connected to gear 106 which is rotatable by a motor 107 as indicated by dashed line 108. Motor 107 is controlled by

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pulses generated by amplifier 109. Computer 84' operatively controls amplifier 109 in the manner described in conjunction with Figure 5 by circuit components not illustrated in Figure 14.

5 The apparatus illustrated in Figure 14 can cause burner 40' to traverse between points C' and D' in the manner illustrated in Figure 15. As burner 40' progresses from point D' toward C' its axis is initially perpendicular to preform axis 42'. When burner 40' reaches point G,
10 motor 107 is energized and begins to rotate burner 40' so that the axis thereof intersects axis 42' but is no longer perpendicular thereto. For example, the axis of burner 40' could be tilted upwardly along the preform as illustrated in Figure 15; alternatively, the axis of burner 40'
15 could be tilted downwardly when it reaches the upper extreme position along its path. Also, the soot stream from burner 40' can be directed downwardly beyond end surface 49', or upwardly along the preform when the burner reaches point C'.

20 Another modification illustrated in Figure 15 eliminates the need to employ separate axial burners to form the inner core region of the preform. As burner 40' travels from point D' and arrives at some point such as point G, it begins to travel along an arcuate path represented by dashed line 110. It continues along path 110
25 until it reaches point C", which may coincide with the previously described position of an axial burner. During its movement along path 110, the burner may tilt upwardly or downwardly as described above. Upon reaching point C",
30 the burner may be directed at surface 49' and reside for a time sufficient to extend the length of surface 49' by the required amount. Burner 41' could follow a similar arcuate path near the end of the preform.

35 The apparatus illustrated in Figure 3 could be modified to cause a burner to traverse a path having linear and arcuate sections. The lower section of vertical shaft 68

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would be curved toward preform axis 42. Bushings 72 would have to be sufficiently short that they would not bind on the curved section of shaft. Reversing mechanism 73 would continue to move in a linear, vertical path. However, mechanism 73 would be connected to plate 71 in such a manner that vertical movement of mechanism 73 could cause vertical movement of plate 71, but mechanism 73 could slide horizontally with respect to plate 71. Such a modification to the apparatus of Figure 3, coupled with the burner rotating mechanism of Figure 14 would enable a burner to move reciprocatingly along a linear path between points D' and G, for example, and then move along an arcuate path 110 to point C" while directing a soot stream toward end portion 49' of the preform core member.

The two or more longitudinally traversing burners 40' and 41' need not traverse between the same two end points. For example, burner 41' could stop at point C' while burner 40' traverses longitudinally to point C". Also burner 40' could traverse upwardly to point D" while burner 41' traverses beyond that point to point D'. Point D" could be selected such that the dopant concentration tapers to zero at the edge of the core.

The embodiments illustrated in Figures 10, 11, 14 and 15 should ensure better blending of soot during deposition to prevent or minimize undesirable soot density and composition changes.

Some other modifications to the first described embodiment are as follows. A burner could emit soot, the composition of which comprises a base glass and two or more dopants. For example, a burner depositing SiO_2 doped with GeO_2 and P_2O_5 would allow the fabrication of an optical fibre having lower dispersion. In addition to varying burner velocity, the amounts of one or more

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constituents could vary with burner position as disclosed in U.S. Patent 4,378,985. Three or more lateral moving, variable speed burners could be employed, each depositing soot having a different composition.

5 In the embodiment of Figure 16 a coating 111 of soot is deposited on mandrel 112 by burners 40' and 41'. A coating 113 is deposited on the surface of coating 111 by burner 55'. Mandrel 112 may be formed of a material
10 such as glass, ceramic or the like having a coefficient of expansion compatible with that of the deposited material. Mandrel 112 is rotated and longitudinally translated as indicated by arrows 114 and 115 by chuck 116. Burners 40' and 41' reciprocate between
15 positions C and D, and burner 55' reciprocates between positions E and F. This figure illustrates the embodiment wherein the extent of traverse of burner 55' does not overlap the extent of traverse of burners 40' and 41'. If mandrel 112 is to be removed from the
20 porous preform prior to consolidation thereof, the mandrel surface may be coated with a layer of carbon soot prior to the deposition of glass soot thereon as described in U.S. Patent No. 4,233,052.

After the preforms produced in accordance with the
25 aforementioned methods have reached a suitable length, they may be removed from the deposition apparatus and transported to a consolidation furnace where they are heated to a temperature sufficiently high to consolidate the glass soot particles and form a solid glass optical
30 waveguide draw blank. If the mandrel is removed from the preform prior to drawing, the entire fibre core may be formed of glass deposited by the moving burners 40' and 41' (see Figure 16). Alternatively, the initially provided mandrel 112 of Figure 16 may form the central

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core region while the glass deposited by burners 40' and 41' forms the outer portion of the core.

To produce an optical waveguide fibre, continuously, an apparatus such as that illustrated in Figure 17 may be employed. This apparatus is similar to that describes in U.S. Patents Nos. 4,230,472 and 4,310,339. Soot preform 117 is supported and rotated by means 118 while it is longitudinally translated thereby in the direction of arrow 119. Means 118 may comprise, for example, a plurality of rollers surrounding preform 117 and mounted so as to support, rotate and translate the structure. Such support rollers means are well known in the art. Heaters 121 heat the porous preform to a temperature sufficient to consolidate it into a solid glass rod 122. The consolidated rod is supported and rotated by means 123 which is similar to the aforementioned means 118. The consolidated rod 122 passes between heaters 124 where the temperature thereof is raised to the drawing temperature of the material thereof and is drawn into an optical waveguide fibre 125 which is wound on reel 120. Thus, a preform being formed in accordance with the present invention may be simultaneously drawn into a fibre.

Figure 18 shows a fragmentary view, in partial cross-section, of a porous preform formed by the apparatus of any of the above-described embodiments. Conically shaped layers 128 are disposed on cylindrically shaped starting member 129. Each of the layers 128 is formed of two sublayers. Sublayers illustrated by a dense dot pattern have high dopant concentration. Sublayers illustrated by a sparse dot pattern represent a region containing little or no dopant. While starting member 129 is shown in a different type of cross-section, that member could be an axially formed porous structure of the type illustrated in Figure 1 or a solid mandrel of the type illustrated in Figure 16. The thicknesses of the sublayers vary with

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preform radius. Somewhere along the extent of each layer, the positions of the sublayers are reversed due to the crossing of the burners which form those sublayers.

5 For example, the layer represented by the dense dot pattern may consist of SiO_2 doped with GeO_2 . The layer represented by a sparse dot pattern may consist of pure SiO_2 . The refractive index at any radius within a particular layer depends upon the relative
10 thicknesses of the two differently doped sublayers within the layer. In an optical waveguide preform, the GeO_2 -containing sublayer within each layer has a greater thickness near the centre of the preform. This is caused by the slower movement of the burner which
15 deposits the GeO_2 containing soot as it forms that portion of the conically shaped layer which has a relatively small radius.

 Conically shaped layers 130 of low refractive index material are formed on the outer surface of the
20 preform section formed by layers 128. The sparse dot pattern of layers 130 indicates that they are formed of a material having little or no refractive index-increasing dopant. This outer or cladding region of the preform could also be formed of a base glass such as
25 SiO_2 doped with a material such as B_2O_3 which decreases the refractive index of the base glass. The number of layers 130 can be equal to or different from the number of layers 128, and the pitch of these two layers can be the same or different, depending upon the speeds of the
30 burners depositing the layers and the amount of soot deposited per pass.

 The method of the present invention can also be employed to form cylindrically shaped layers. Referring to Figure 19, burners 133 and 134 continuously
35 traverse the same longitudinal portion of rotating

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mandrel 135. Burner 133 produces a stream of soot, the composition of which is such that it has a relatively high refractive index. Burner 134 produces a stream of soot, the composition of which is such that it has a relatively low refractive index. When layers of relatively small radii are being formed, the burner producing the high refractive index soot moves more slowly than that which produces the relatively low refractive index soot. This burner speed ratio is gradually changed as preform radius increases, the relative thickness of the high refractive index soot sublayer becoming smaller with increasing radius. Toward the outer portion of the core region of the preform, the thickness of the low refractive index soot sublayer is greater than that of the high refractive index soot sublayer. Referring to Figure 20, first, second and third layers 137, 138 and 139 of soot are consecutively applied to starting member 135. As discussed in connection with Figure 18, soot having a relatively high refractive index is represented by a dense dot pattern while that having a relatively low refractive index is represented by a sparse dot pattern. Since layers having relatively small radii must have a relatively high refractive index, the burner which produces the soot having relatively high refractive index moves more slowly than that which produces the relatively low refractive index soot. At the point of crossover of the two burners, the relative radial positions of the relatively high refractive index sublayer and the relatively low refractive index sublayer within a particular layer are reversed. The crossover point can occur at different longitudinal positions along mandrel 135 as illustrated in Figure 20. If desired, burners 133 and 134 can simultaneously begin their scan at opposite ends of mandrel 135. Obviously this necessitates the fast moving burner waiting the end

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of its scan so that the slow burner can finish its traverse before the two burners again simultaneously begin their traverse.

CLAIMS:

1. A method of forming a porous preform, comprising the steps of rotating an elongate cylindrical core member about its longitudinal axis; and depositing a plurality of layers of glass particles on said core member to build up a first coating of given thickness thereon, wherein each of said layers is formed by directing toward the lateral surface of said core member a first stream of glass particles having a predetermined composition, reciprocatingly moving said first stream along a given length of said core member at a velocity which is a predetermined function of the radius of that part of the first coating that is being deposited, directing toward the lateral surface of said core member a second stream of glass particles having a composition different from said predetermined composition, and reciprocatingly moving said second stream along a length of said core member which includes said given length at a velocity which is a predetermined function of the radius of that part of the first coating that is being deposited, the velocity function of said first stream being different from that of said second stream.
2. A method according to claim 1, wherein the velocity of each of said streams is a function of the radius of the layer being deposited, the velocity versus radius function of said first stream being different from that of said second stream.
3. A method according to claim 2, wherein said first stream deposits a base glass and said second stream deposits a base glass and at least one dopant to increase the refractive index thereof to a value greater than that of said base glass, the velocity of said first stream decreasing as the radius of said preform increases, and the velocity of said second stream increasing as the radius of said preform increases.

4. A method according to claim 3, wherein the instantaneous direction of movement of said first stream is opposite that of said second stream.

5. A method according to claim 1, further comprising the step of longitudinally moving said core member in one direction, the velocities of said first and second streams varying as functions of the positions of said streams along their paths of movement, the velocity versus position function of said first stream being different from that of said second stream, the combined deposition of said first and second streams building up in the region of reciprocating movement of said streams a coating of thickness which tapers from zero thickness to said given thickness.

6. A method according to claim 5, wherein the compositions of said first and second streams are constant with respect to time.

7. A method according to claim 6, wherein said first stream deposits a base glass and said second stream deposits a base glass and at least one dopant to increase the refractive index thereof to a value greater than that of said base glass, the velocity of said first stream decreasing as it moves from the region of zero thickness toward said given thickness, and the velocity of said second stream increasing as it moves from the region of zero thickness toward said given thickness.

8. A method according to claim 5, 6 or 7, wherein the core member is an elongate rod of high purity glass having a refractive index greater than that of said first coating.

9. A method according to claim 5, 6 or 7, wherein the core member comprises a temporary mandrel, said method further comprising the step of depositing a second

adherent coating of glass particulate material on the surface of said first coating, the refractive index of said second coating being less than that of said first coating, removing said temporary mandrel to form a porous preform, heating said porous preform to sinter or consolidate it thereby forming a solid blank, further heating the structure so formed to the drawing temperature of the materials thereof, and drawing the heated structure so formed to reduce the cross-sectional area thereof and form a substantially continuous optical waveguide fibre.

10. A method according to claim 5, wherein the instantaneous direction of movement of said first stream is opposite that of said second stream.

11. A method according to claim 5, wherein the cylindrical core member is provided by providing a starting member having at least one end surface, applying an adherent coating of glass particles to said end surface and longitudinally translating said starting member while continuously applying said adherent coating of particles to continuously form the end portion of said core member.

12. A method according to claim 11, wherein the refractive index of said core member is greater than the refractive index of any part of said first coating.

13. A method according to claim 11, further comprising the step of directing a third stream of glass particulate material toward a lateral surface of said first coating to build up a second coating of glass particles thereon, the refractive index of said second coating being lower than that of said core member and said first coating.

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14. A method according to claim 13, further comprising the steps of continuously feeding the resultant preform into a high temperature furnace to consolidate it, thereby forming a solid blank, further heating the structure so formed to the drawing temperature of the materials thereof, and drawing the heated structure so formed to reduce the cross-sectional area thereof and form a substantially continuous optical waveguide fibre.

15. A method according to claim 11, wherein the path of reciprocation of at least one of said streams extends beyond the end of the core member.

16. A method according to claim 15, wherein the step of applying an adherent coating of glass particles to said end surface comprises directing a fourth stream of glass particles toward said end surface and oscillating the source of said fourth stream about said end surface so that said fourth stream is directed at different angles onto the end portion of said core member.

17. A method according to claim 16, wherein the oscillation of said fourth stream is synchronized with the reciprocation of said first and second streams, said fourth stream being directed toward the end portion of said core member from a side thereof that is remote from the side thereof onto which said first or second stream is directed.

18. A method according to claim 11, wherein at least one of said first and second streams is directed perpendicular to the longitudinal axis of said core member during its reciprocating movement except during that time in which said stream is at or near the end of its traverse when the axis of said stream becomes orientated in a direction other than perpendicular to said longitudinal axis.

19. A method of forming a porous glass preform comprising the steps of: providing a starting member having an axis of rotation on which is situated an end surface, rotating said starting member about said axis, directing at least one stream of glass particles onto said end surface to build up an adherent coating of particles thereon, and longitudinally moving said starting member to maintain the newly formed portion of said adherent coating a substantially fixed distance from the source of said at least one stream, continued deposition of said particles and longitudinal movement of the resultant build up forming a porous, cylindrical member having a continuously formed end portion characterized by oscillating the source of said at least one stream about said end surface portion so that said stream is directed at different angles onto the end portion of said porous, cylindrical member, directing a lateral stream of glass particles toward said porous, cylindrical member, and reciprocatingly moving said lateral stream with respect to a portion of the length of said cylindrical member to deposit and build up in the region of reciprocating movement of said lateral stream, a coating of thickness which tapers from a maximum thickness to zero thickness, the oscillatory movement of said at least one stream being synchronized with the reciprocating movement of said lateral stream so that said at least one stream is directed toward the end portion of said porous, cylindrical member from a side thereof that is remote from the side thereof onto which said lateral stream is directed.

20. A method of forming a porous glass preform comprising the steps of providing an elongate cylindrical core member, rotating said core member, longitudinally moving said core member, directing a first stream of glass particles toward a lateral surface of said core member to build up a first coating of given thickness thereon, and continuously reciprocating said stream of particulate material with

respect to a portion of the length of said core member to deposit and build up in the region of reciprocating movement of said stream a coating of thickness which tapers from said given thickness to zero thickness, characterized in that said stream is directed perpendicular to the longitudinal axis of said core member during its reciprocating movement except during that time in which said stream is at or near the end of its path of reciprocation when the axis of said stream becomes orientated in a direction other than perpendicular to said longitudinal axis.

21. A method according to claim 20, wherein the step of providing a cylindrical core member comprises providing a starting member, rotating said starting member, moving said starting member along its axis of rotation, and applying an adherent coating of glass particles to said starting member, the continued application of said adherent coating combined with the longitudinal movement of said starting member causing the formation of a porous, cylindrically-shaped core member, the continuously formed end portion of which is located on or near a plane that is perpendicular to said axis of rotation.

FIG. 5

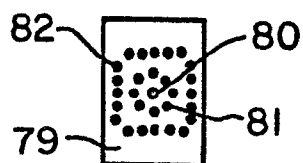
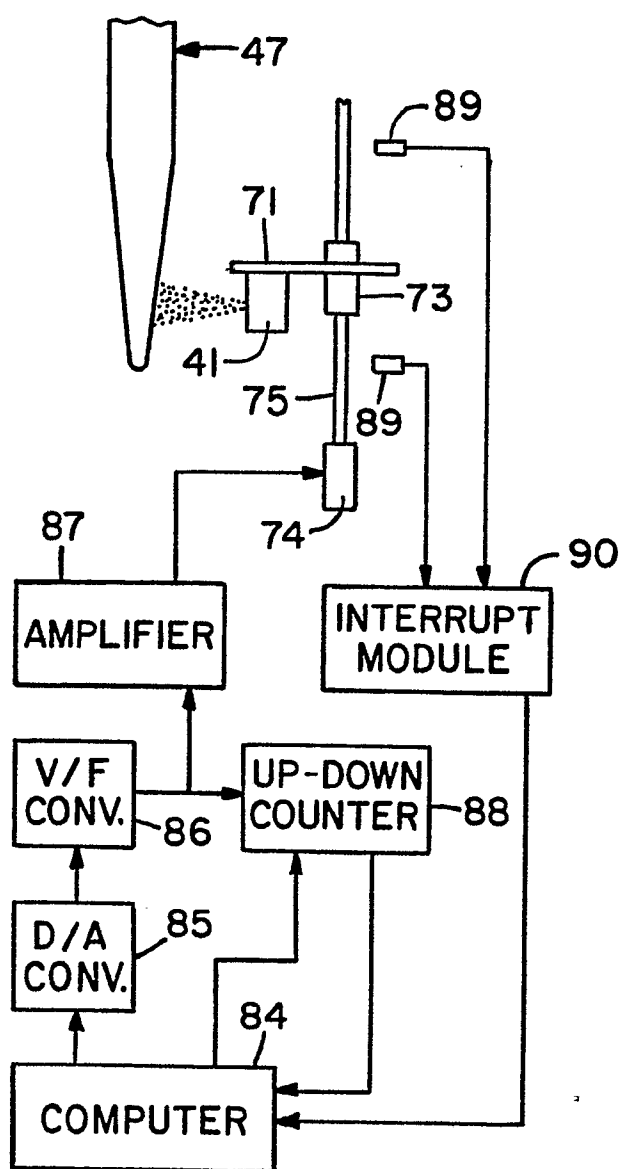


FIG. 4

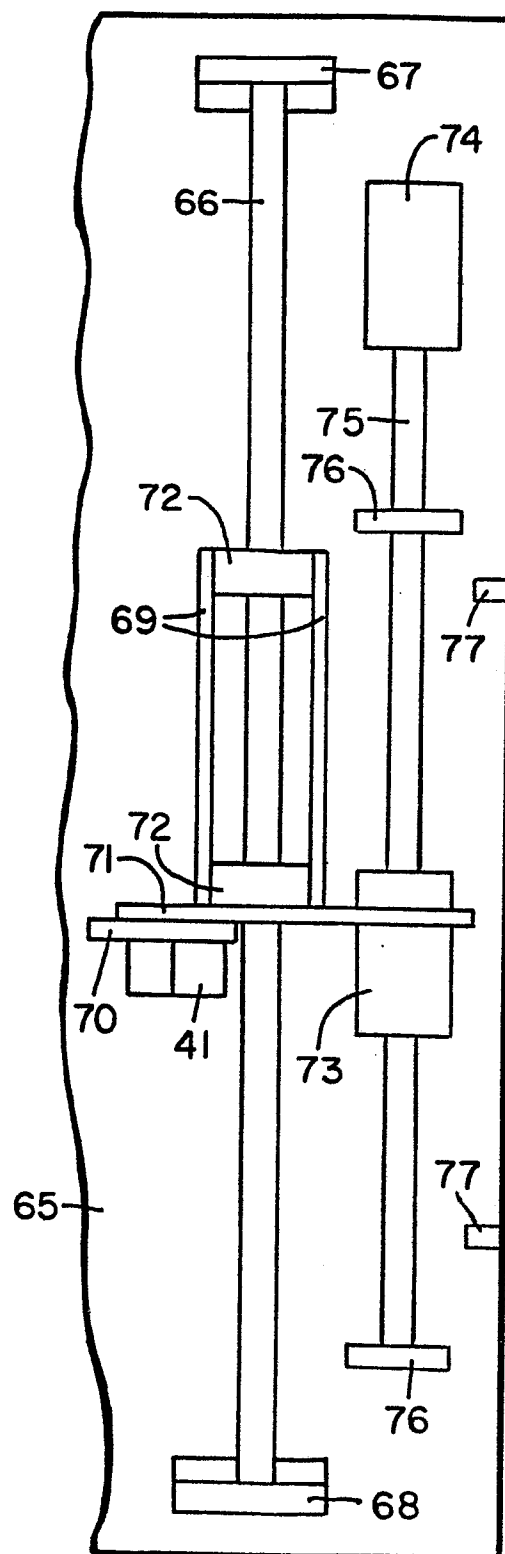


FIG. 3

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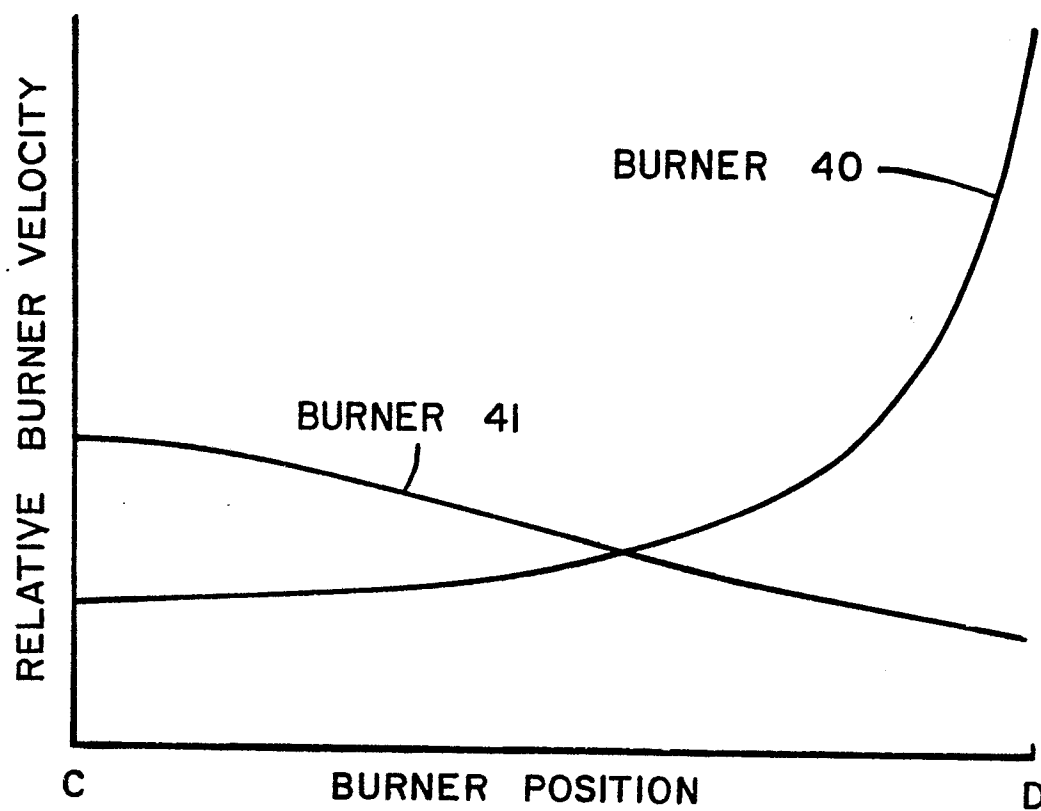


FIG. 6

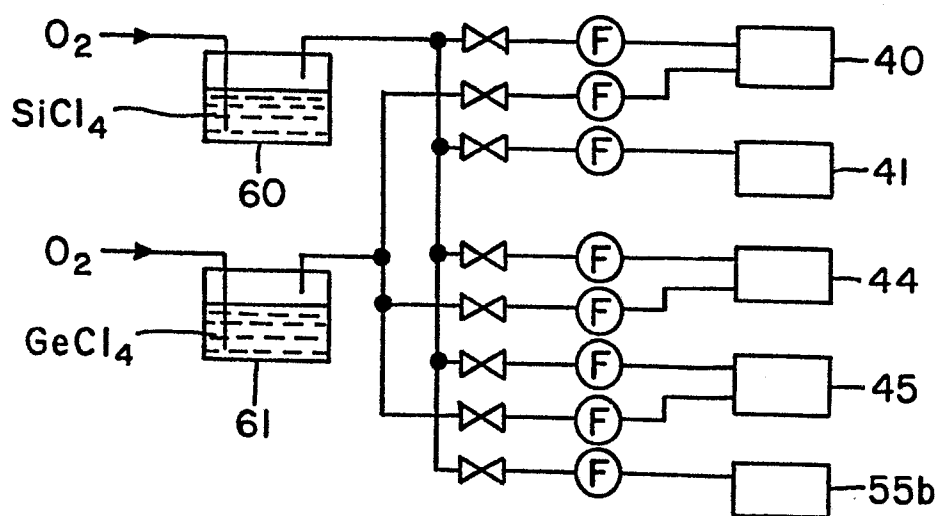


FIG. 7

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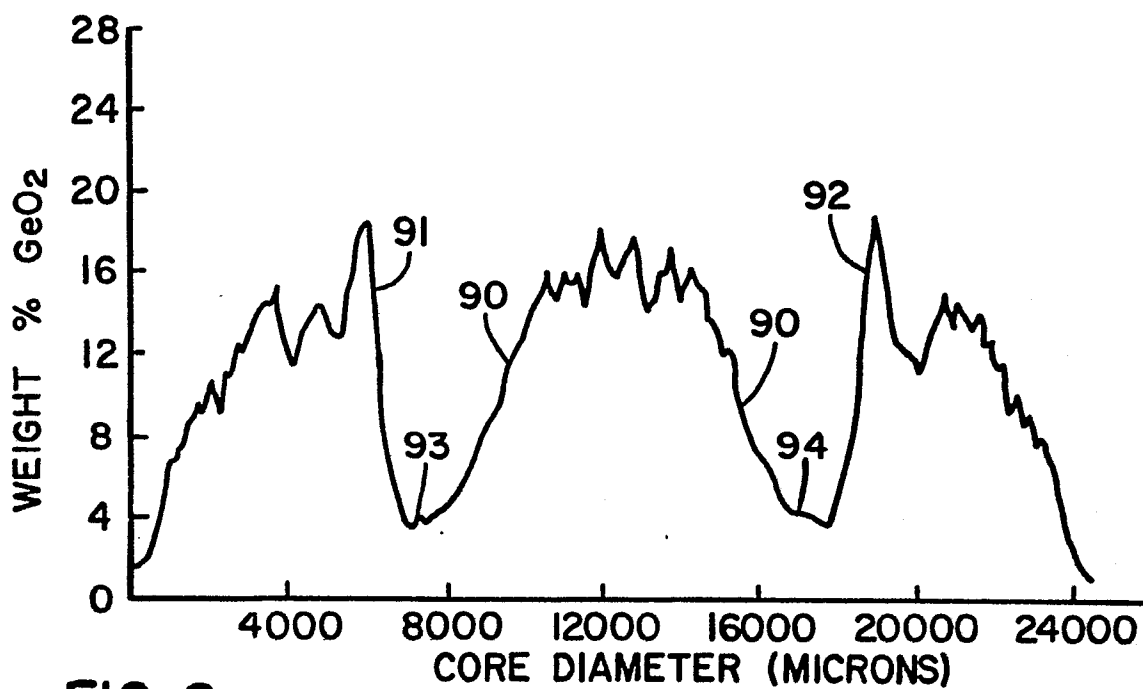


FIG. 8

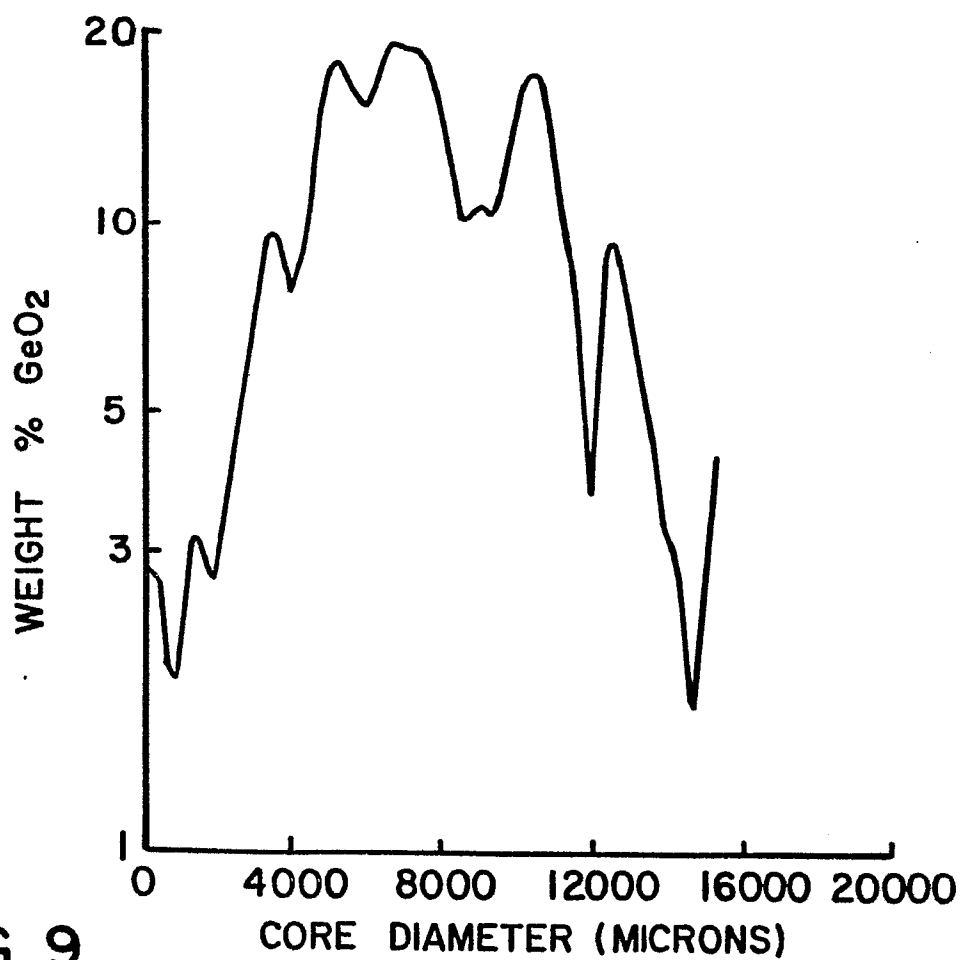


FIG. 9

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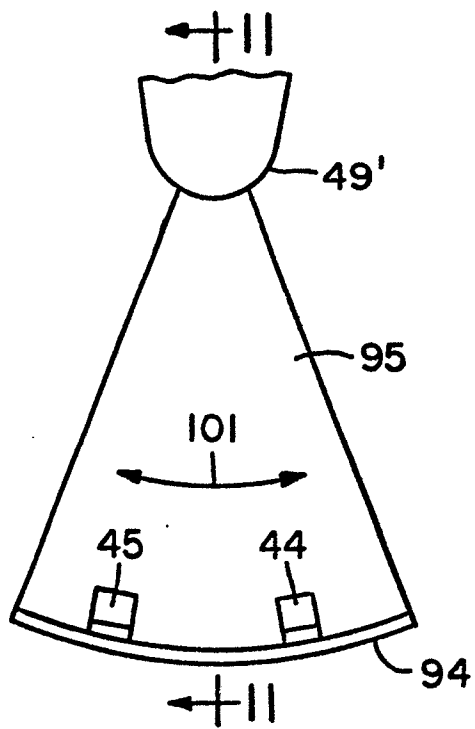


FIG. 10

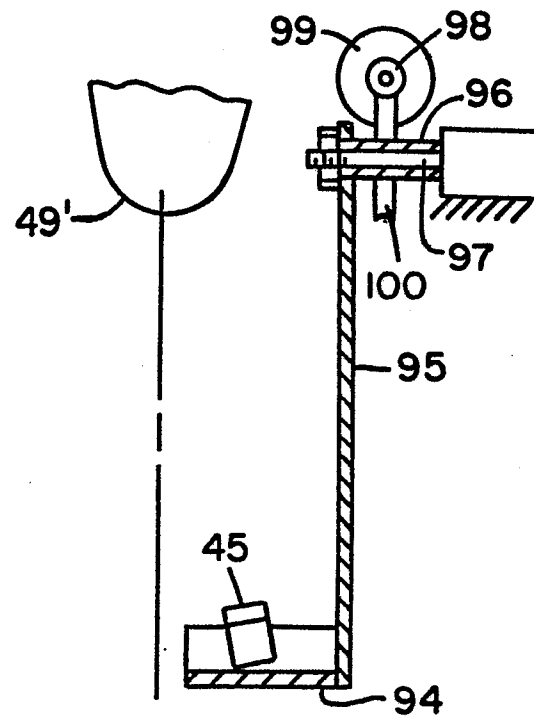


FIG. 11

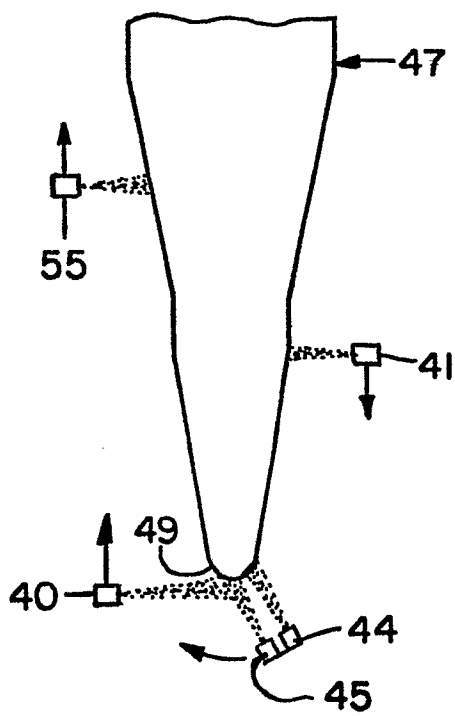


FIG. 12

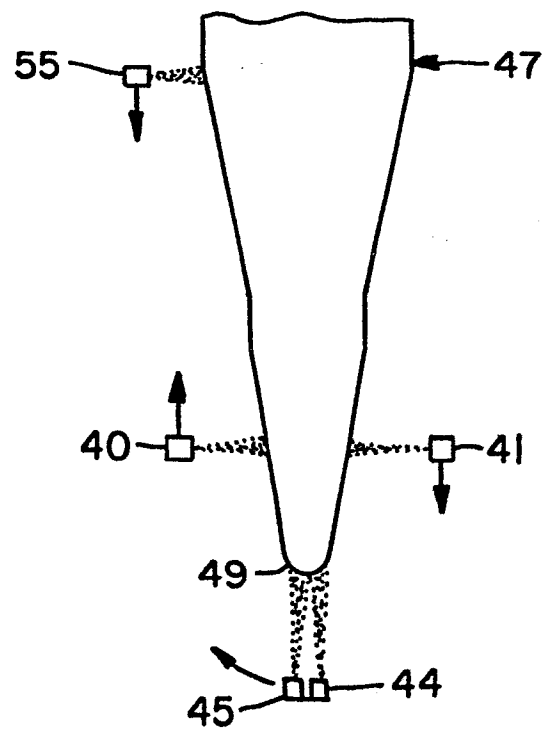


FIG. 13

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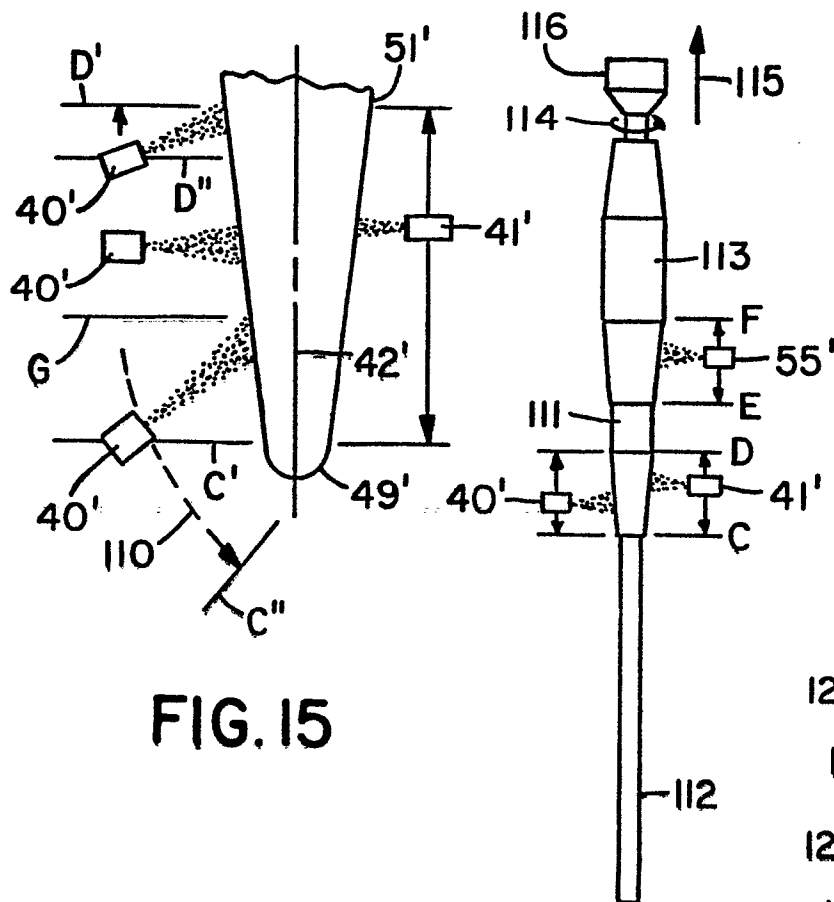
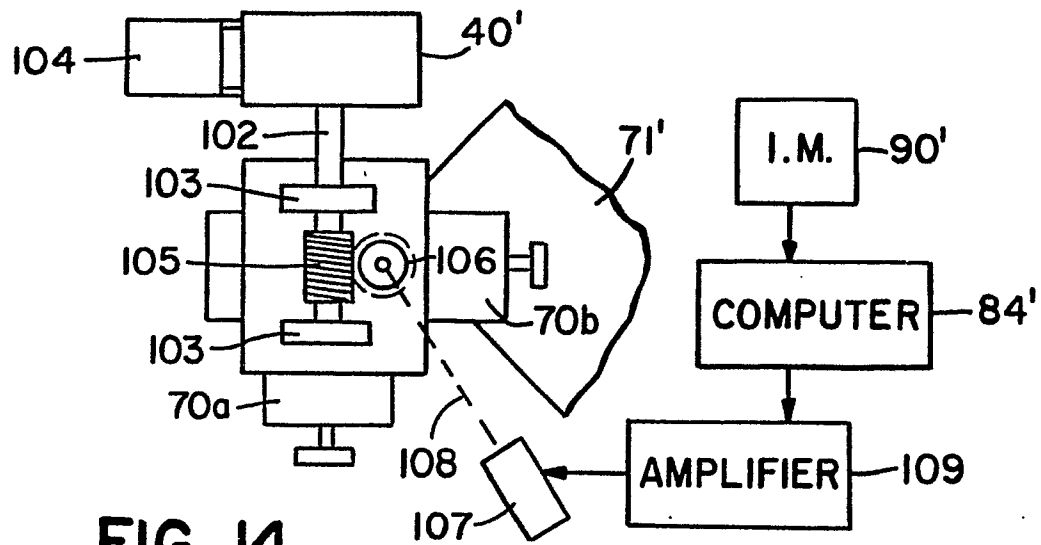


FIG. 16

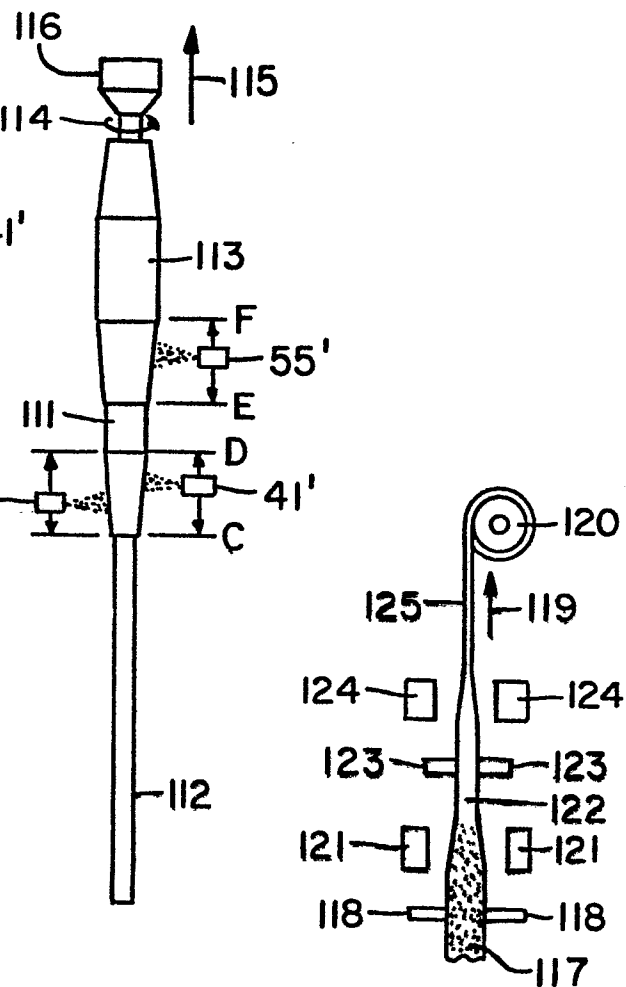
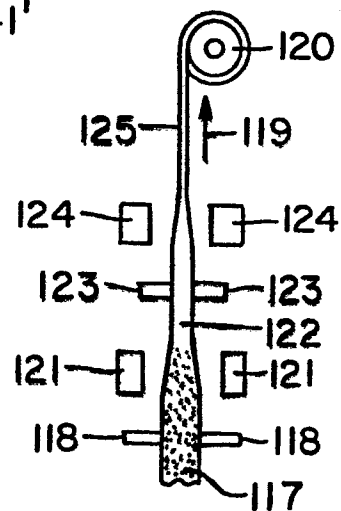


FIG. 17



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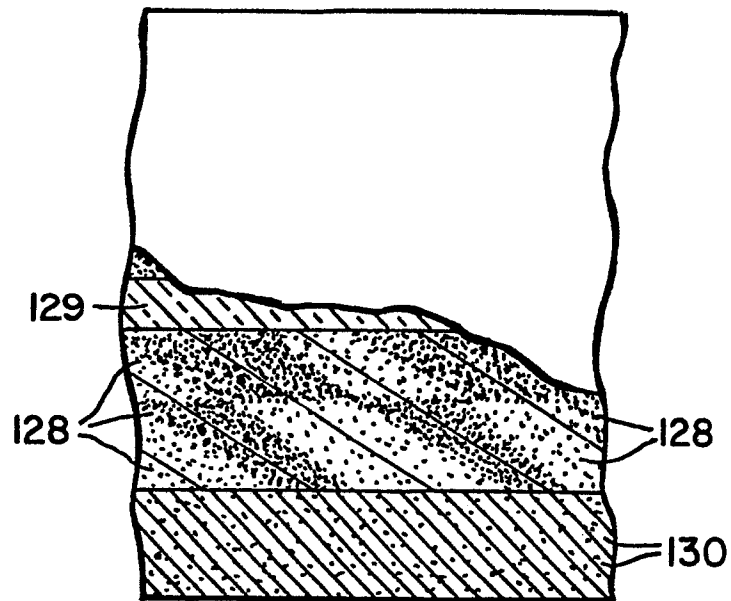


FIG. 18

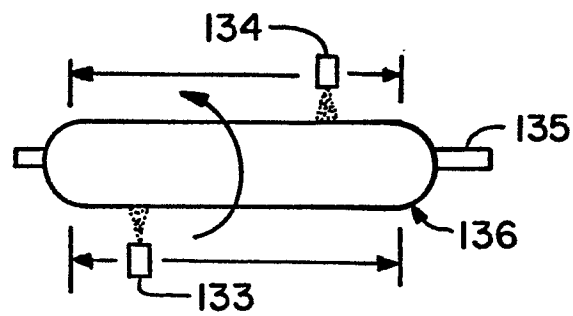


FIG. 19

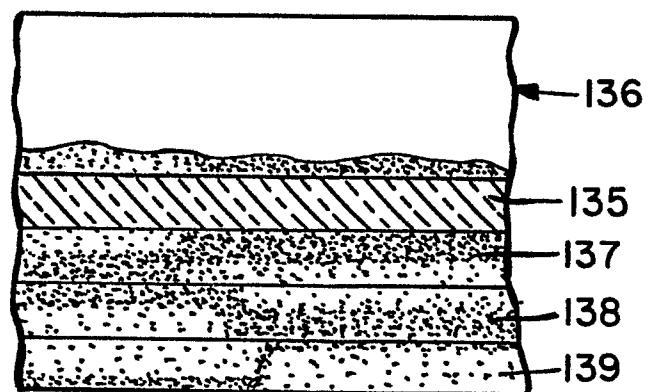


FIG. 20



European Patent
Office

EUROPEAN SEARCH REPORT

0105739

Application number

DOCUMENTS CONSIDERED TO BE RELEVANT			EP 83305922.3
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 7)
P,D, A	US - A - 4 378 985 (POWERS) * Abstract; claims 1-17; fig. 1,2,4; column 3, line 47 - column 4, line 3; column 4, line 22 - column 7, line 32 * -- A PATENT ABSTRACTS OF JAPAN, unexamined applications, C Field, Vol. 6, No. 177, September 11, 1982 THE PATENT OFFICE JAPANESE GOVERNMENT, page 91 C 124 * Kokai-No. 57-92 532 (NIPPON DENSHIN DENWA KOSHA) * --	1,3,5, 7,8,9, 11-14, 16,19 1,4,5, 11,13, 14	C 03 B 37/025 G 02 B 5/14
A,D	US - A - 4 310 339 (BLANKENSHIP) * Claims 1-20; fig. 6,8; column 8, lines 18-30; column 9, lines 28-49 * --	1,9	TECHNICAL FIELDS SEARCHED (Int. Cl. 7) C 03 B G 02 B C 03 C
A,D	US - A - 3 957 474 (KOBAYASHI) * Fig. 3,4; column 6, line 18 - column 8, line 8; claims 1,2, 6 * ----	1,8,11	
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
VIENNA		30-12-1983	HAUSWIRTH
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			